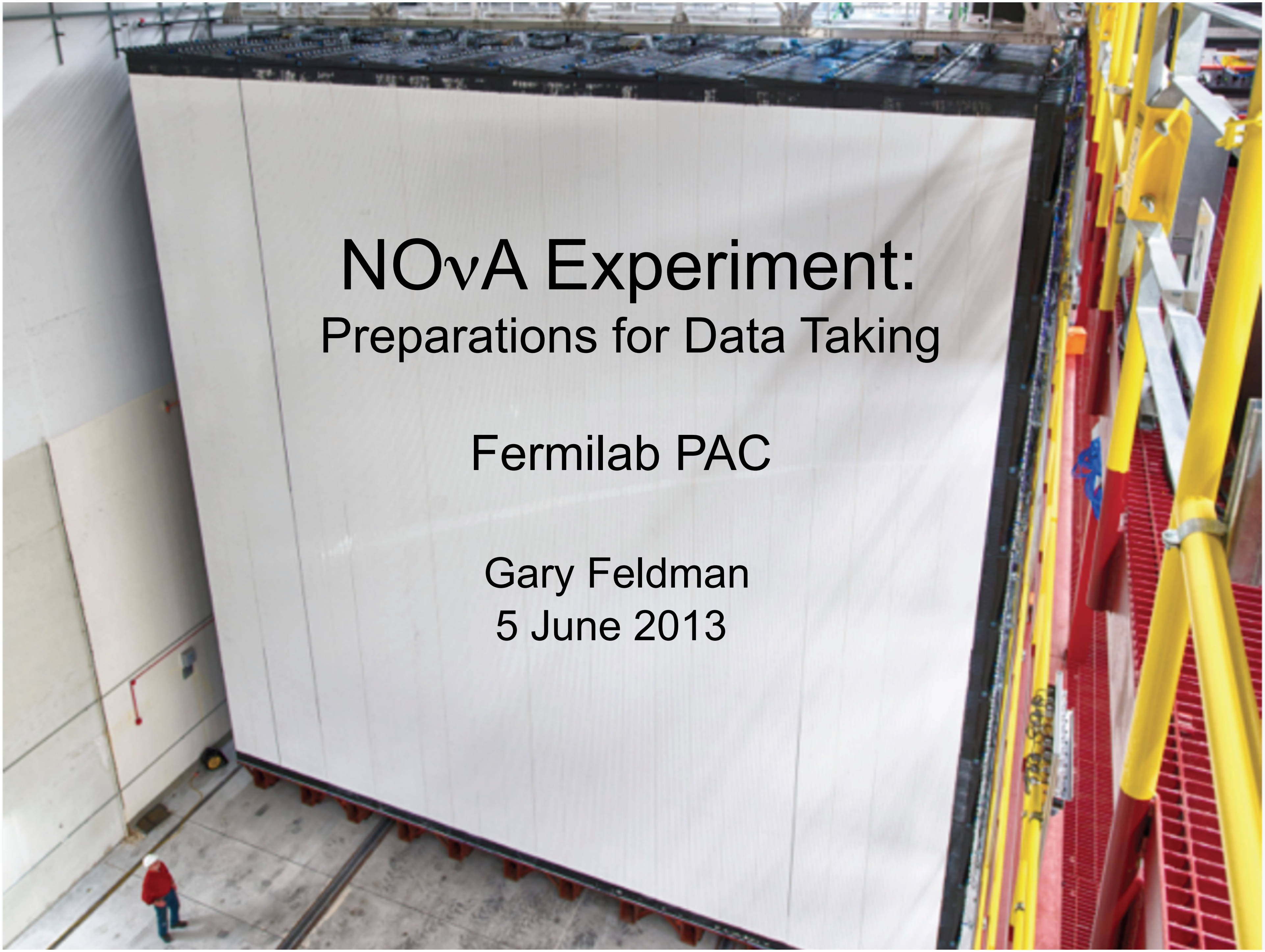


NOνA Experiment:

Preparations for Data Taking

Fermilab PAC

Gary Feldman

5 June 2013

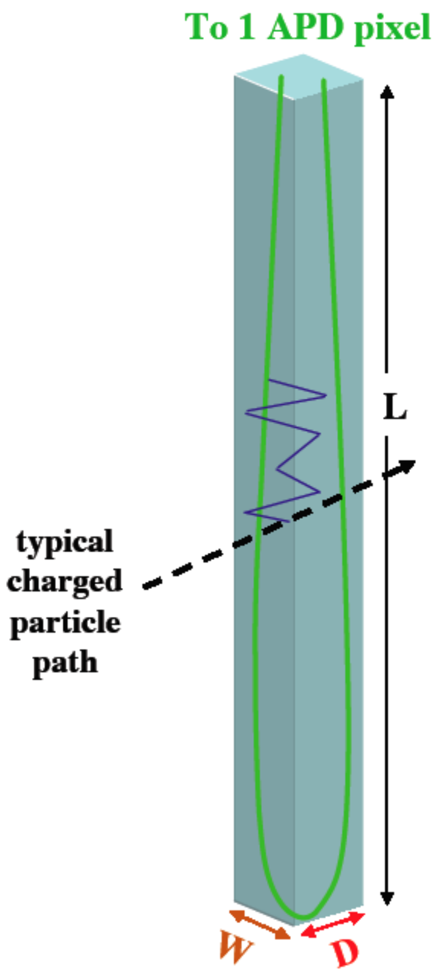
Outline

- Introduction to NOνA
- NOνA Project Update
  - Far Detector
  - Near Detector
  - Accelerator and NuMI Upgrades (ANU)
- NDOS
- Organization
  - Detector Operations
  - Calibration
  - Beam Simulation
  - Detector Simulation
  - Reconstruction
  - ν_e and NC Analysis
  - ν_μ CC Analysis
  - Exotics Analysis
- Data-Driven Triggers

NOνA Overview

- NOνA is a 2-detector ν oscillation experiment, optimized for ν_e identification.
- It has the longest possible base-line, 810 km, for the NuMI beamline in the United States. This maximizes the matter effect, which allows a measurement of the neutrino mass ordering.
- It is sited 14 mr off-axis to produce a narrow-band beam, which reduces backgrounds and increases flux in the oscillation maximum region.

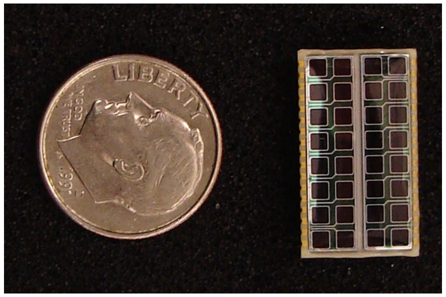
Basic NOνA Detector Element



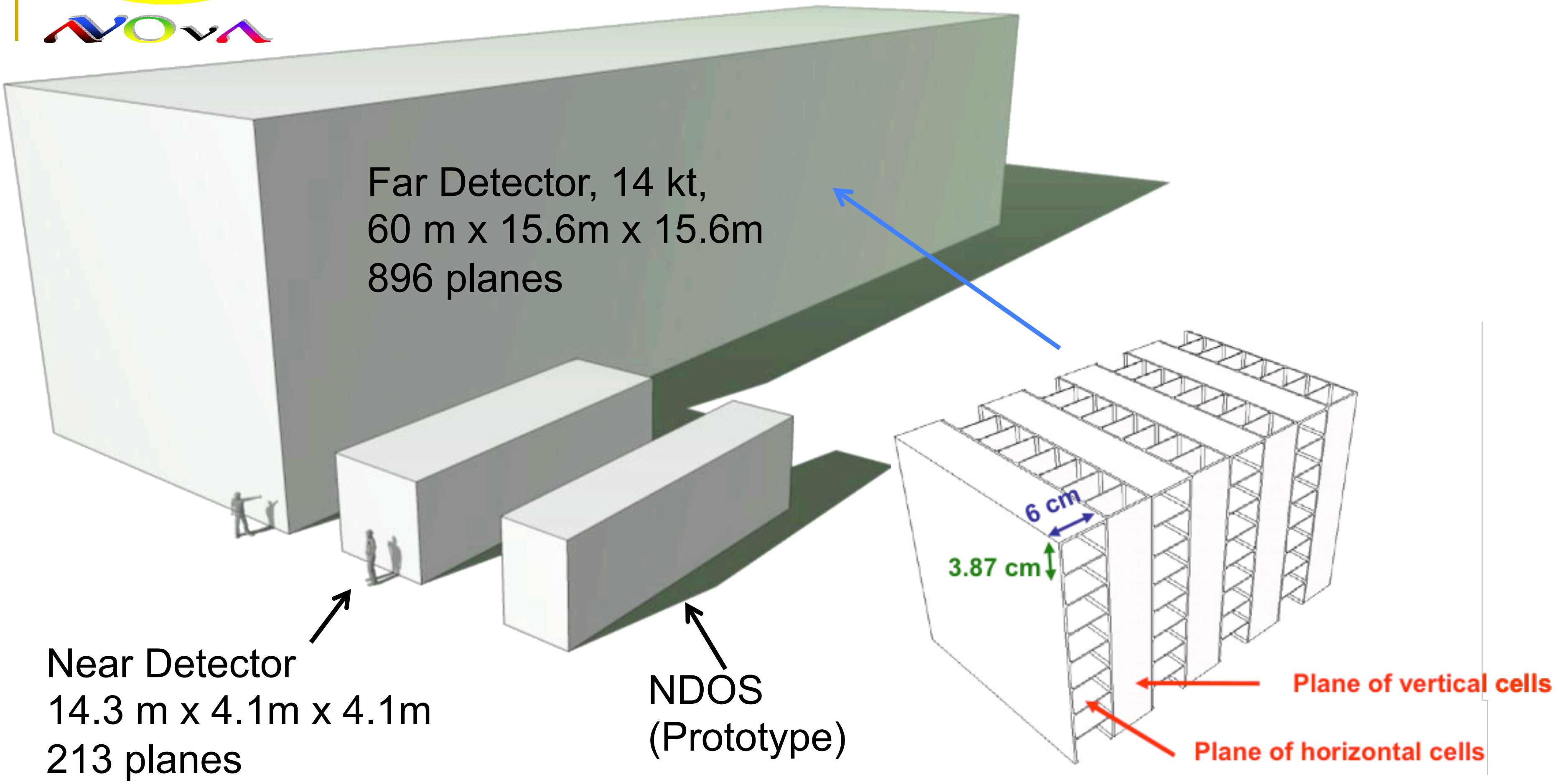
Liquid scintillator in a 4 cm wide, 6 cm deep, 15.7 m long, highly reflective PVC cell.

Light is collected in a U-shaped 0.7 mm wavelength-shifting fiber, both ends of which terminate in a pixel of a 32-pixel avalanche photodiode (APD).

The APD has peak quantum efficiency of 85%. It is run at a gain of 100. It must be cooled to -15^{o}C and requires a very low-noise amplifier.

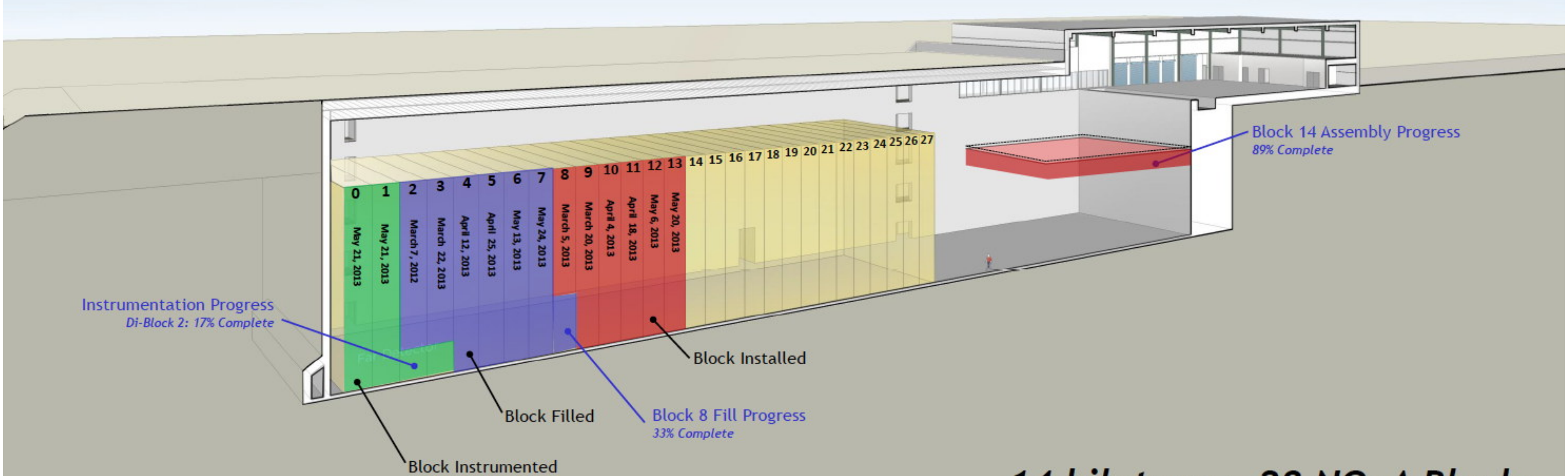


NOνA Detectors



Far Detector Assembly

As of June 3, 2013



14 kilotons = 28 NOvA Blocks

14 blocks of PVC modules are assembled and installed in place

8.33 blocks are filled with liquid scintillator

2.34 blocks are outfitted with electronics

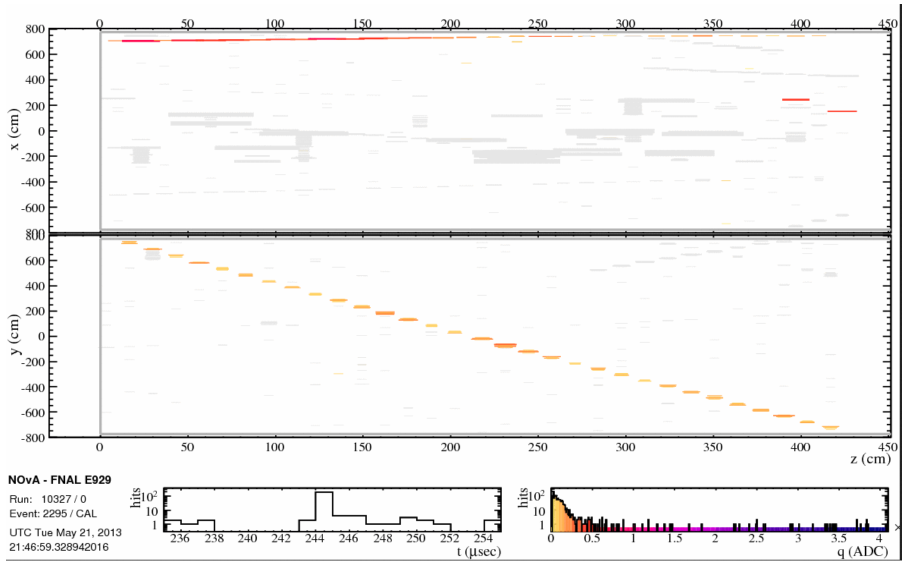
Top of the Far Detector

Photo from May 28, 2013

5 diblocks visible

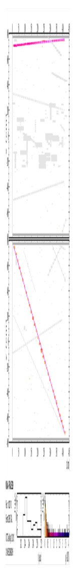
Only the 1st diblock has full APDs installed.

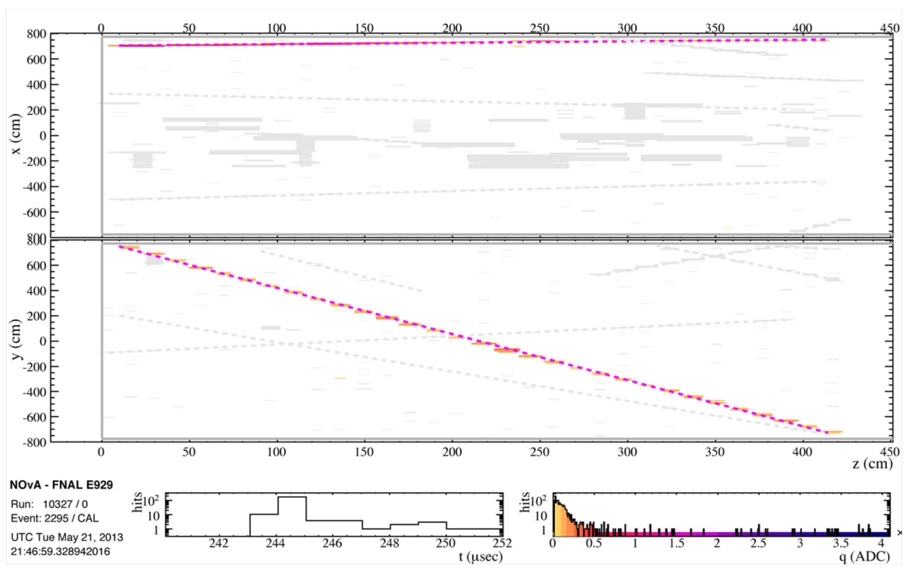
A Vertical Cosmic in the First Diblock of the Far Detector



Raw Data

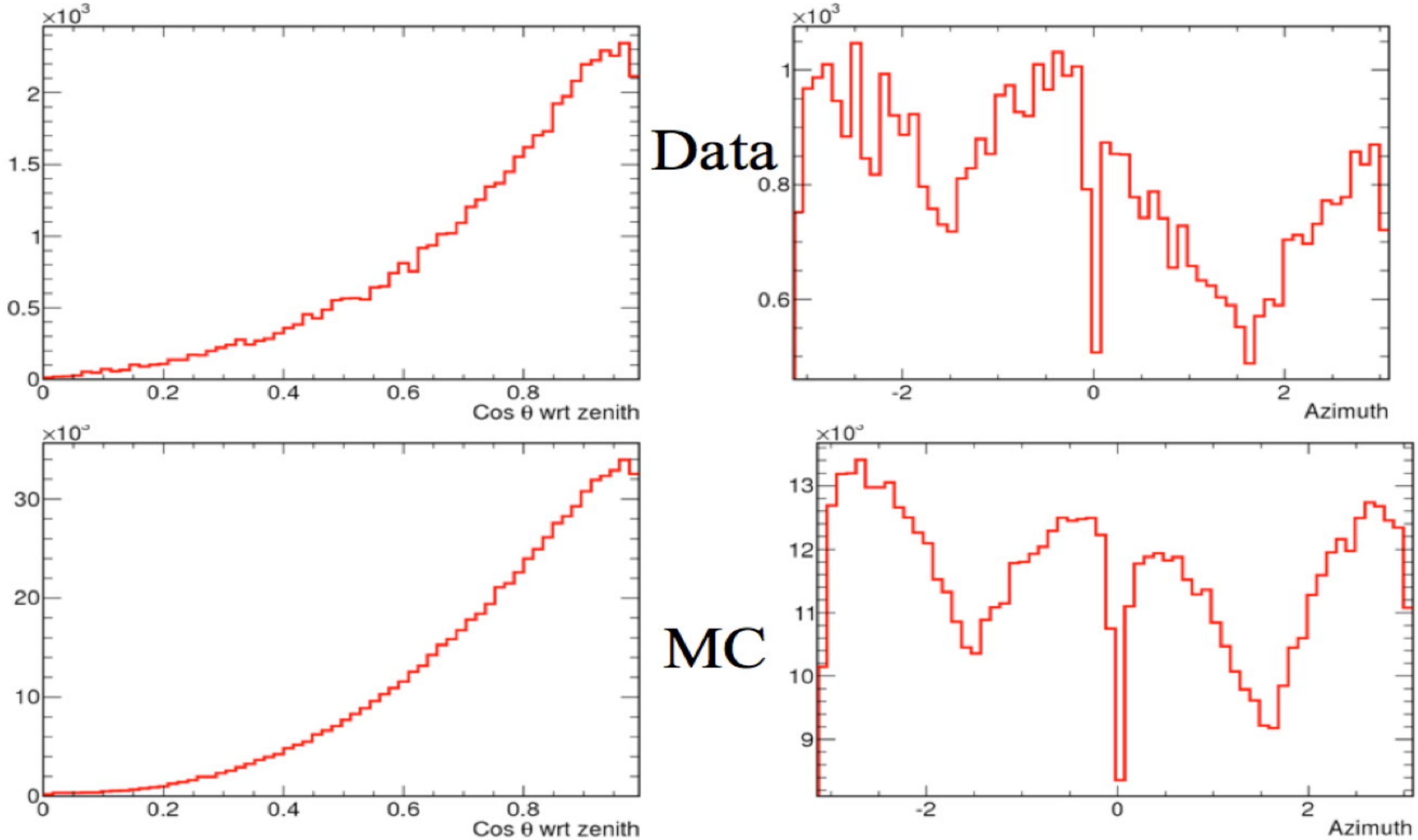
Equal horizontal and vertical scale



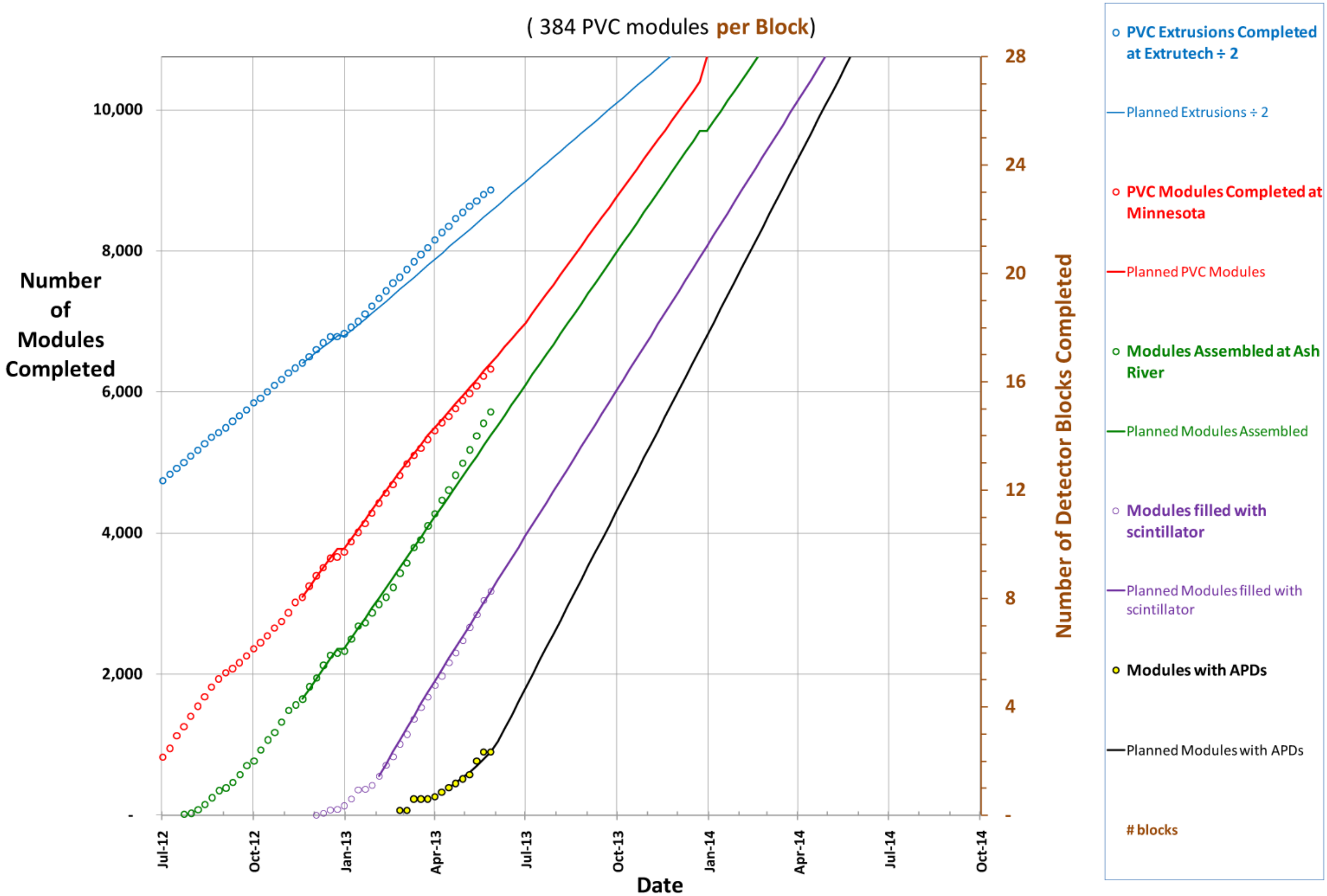


Raw Data with a Fit Track

1st Diblock Track Directions



Far Detector Construction Summary as of June 3



Near Detector Cavern

Near Detector Assembly at CDF

Glue machine

Module Vacuum lifting fixture

Practice dry-stacking with prototype modules

Production Modules

Leak tester

Near Detector Schedule (1)

- The Near Detector schedule is up in the air right now.
  - The problem is that we have a standing army at Ash River doing the Far Detector assembly. For financial reasons, we must keep supplying Ash River with modules from our factory at the University of Minnesota to keep that assembly progressing at full speed.
  - The UM factory got 3 blocks ahead of Ash River by starting earlier. We are using that head start to produce half the modules we need for the Near Detector, so that we can have half a Near Detector in time to use it for data to be presented at the Neutrino 2014 conference.

Near Detector Schedule (2)

- Below is the outfitting schedule for the first half:

		2013 July				August				September				October				November				December			
	Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Muon catcher	Leak test				2	2	2	2																	
	Fill				4	4	4	4																	
	Support structure Install								2	2															
	PDB/DCM install								2	2	2														
	APD cooling install										2	2	2												
	APD dry gas install										2	2	2												
Block 7-8	Leak test									2	2	2	2												
	Fill									4	4	4	4												
	Support structure Install													2	2										
	PDB/DCM install													2	2	2									
	APD cooling install															2	2	2							
	APD dry gas install															2	2	2							
Block 5-6	Leak test														2	2	2	2							
	Fill														4	4	4	4							
	Support structure Install																		2	2					
	PDB/DCM install																		2	2	2				
	APD cooling install																				2	2	2		
	APD dry gas install																				2	2	2		

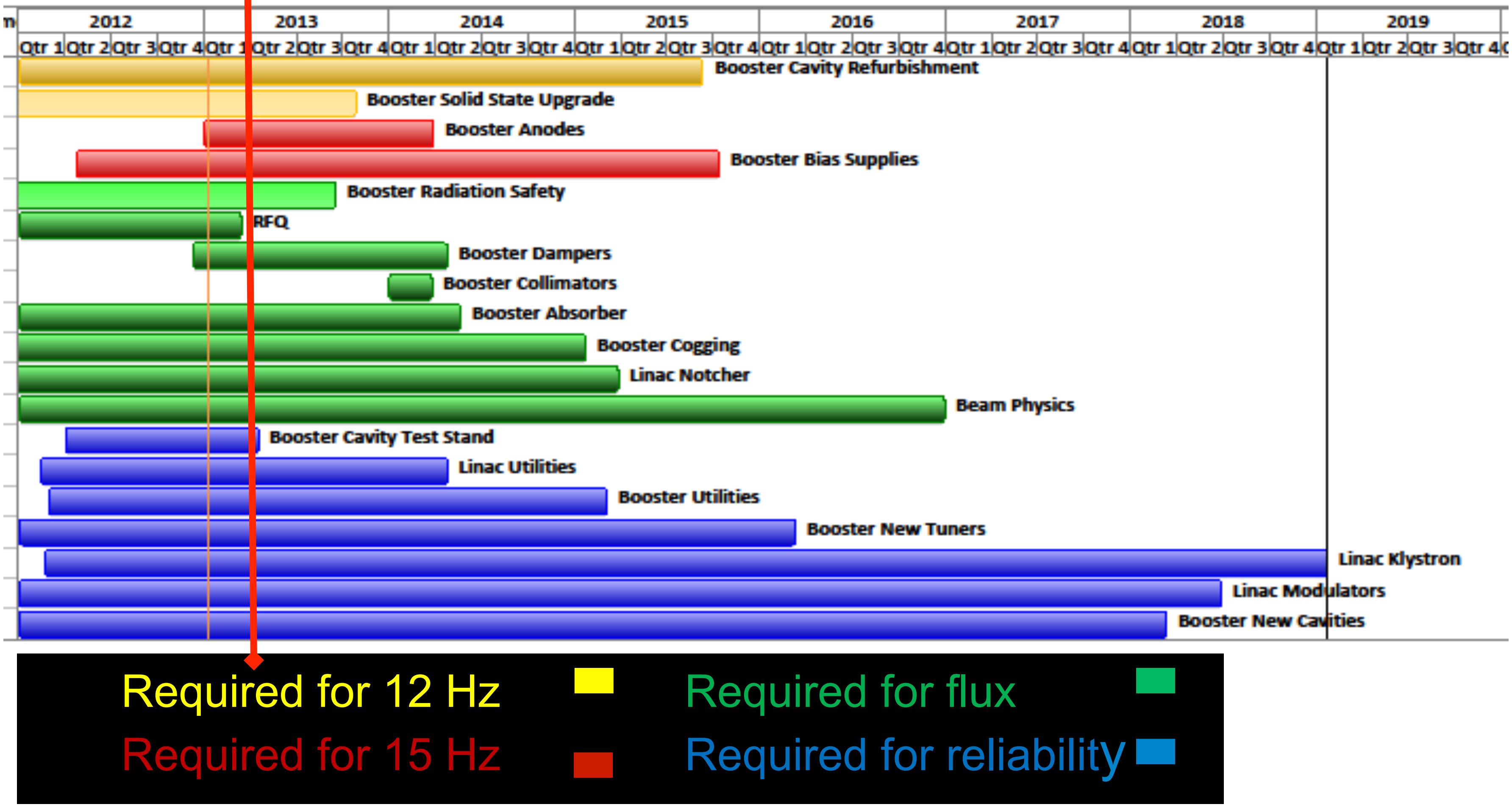
Near Detector Schedule (3)

- When we can produce the other half depends on how fast the UM factory can produce modules, given their fixed infrastructure (again for financial reasons).
  - Time early is February 2014
  - Time late is April 2014

Accelerator and NuMI Upgrades (ANU)

- Originally, the NOνA project just consisted of the detectors. However, the OMB, wanting to insure that there would be an adequate beam for NOνA, added the ANU to the project: improvements to the Recycler and the Main Injector to allow 700 kW of beam power.
- This part of the project will be completed in about 3 weeks.
- Unfortunately, necessary upgrades to the Booster were not included in the ANU. To reach 700 kW, we need 9 Hz from the Booster. However, due to thermal limitations in the Booster RF, at present, it is only capable of 7 Hz, perhaps 7.5 Hz.
- Since this is a "weak link" situation, the Booster will not be able to increase its rate until all of the RF cavities are reworked, and, due to financial limitations, this is not scheduled until late 2015.

PIP Schedule

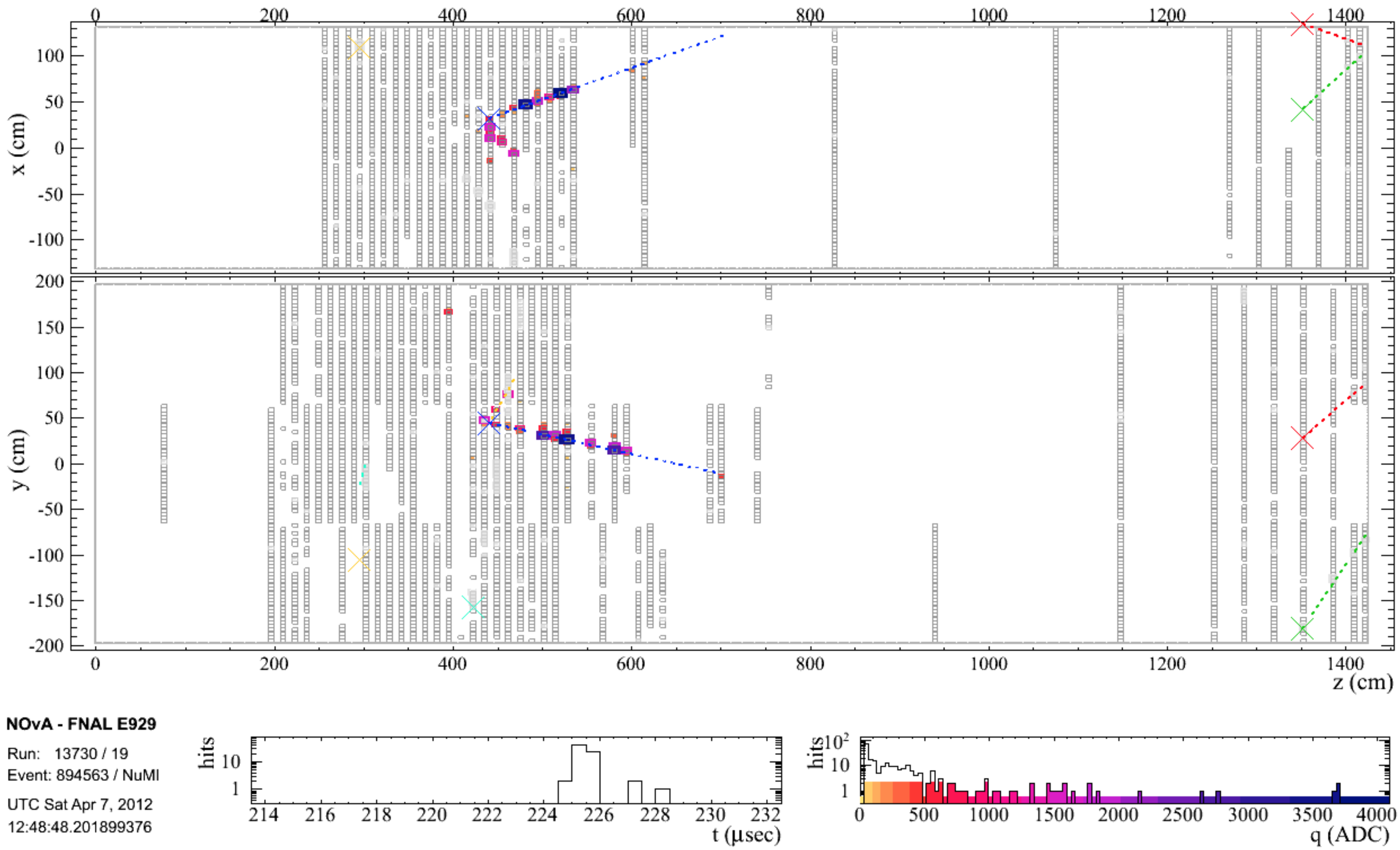


Bill Pellico, April 19, 2013

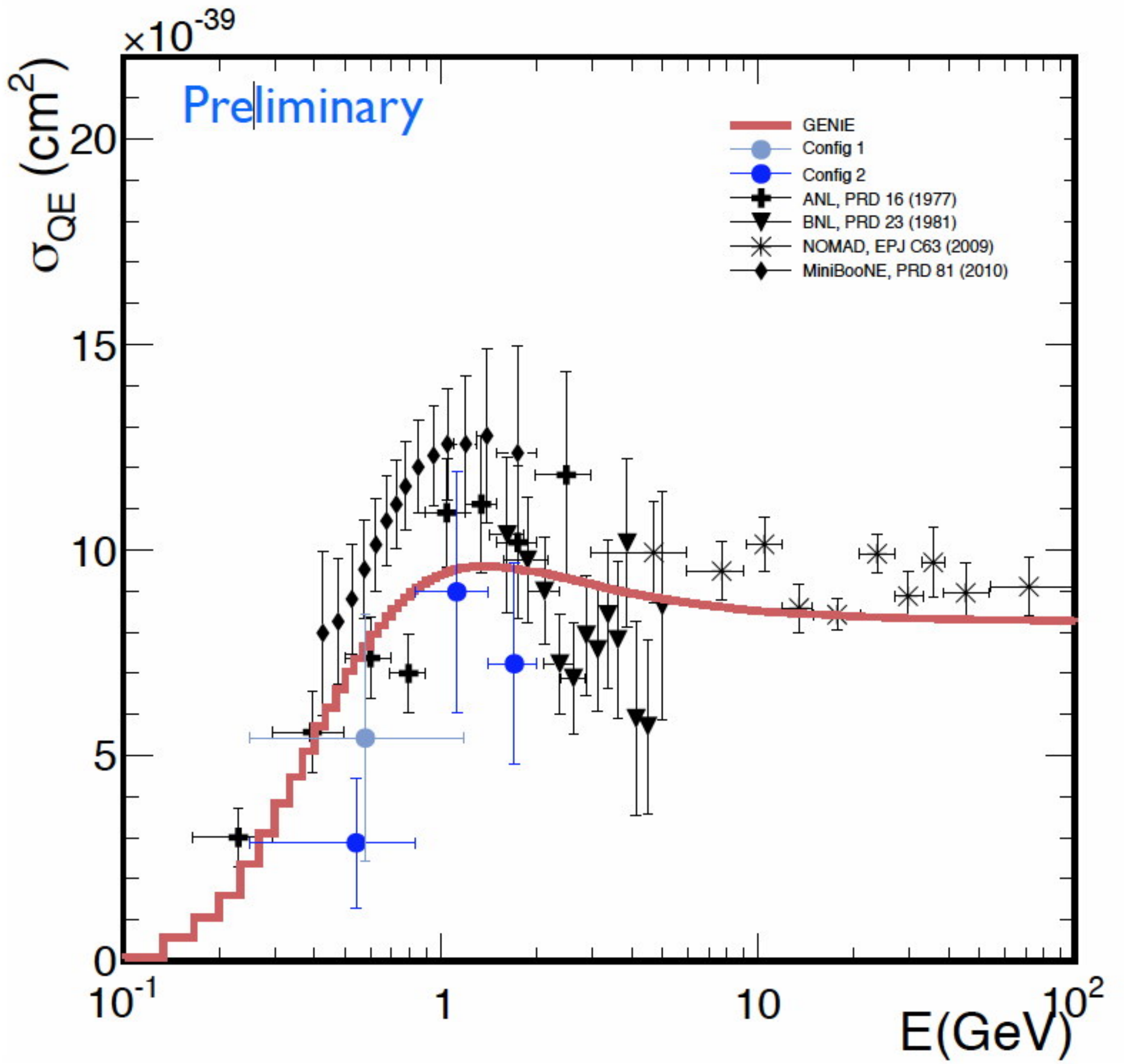
NDOS

- We have been running the NDOS in the off-axis NuMI and Booster beams and cosmics for about 2 ½ years.
- It has been invaluable for two reasons:
  - We learned of mechanical and APD problems, which we have fixed.
  - We have been able to develop the DAQ, DCS, online monitoring, calibration, timing, and offline reconstruction and analysis software (in spite of the APD failures).
    - We have identified beam ν_e events (from *K* decay) 45 events with 18 estimated background.
    - We have two students writing theses on NDOS data, one on hadronic distributions and one on quasielastic cross sections.

ν_e CC QE NDOS Event



Very Preliminary ν_μ CC QE Cross Sections



Organization

- **Spokespeople** Feldman / Messier
  - **Detector Operations** Steven Magill / Jarek Nowak
  - **Calibration and alignment** Tom Coan / Brian Rebel
  - **Computing** Craig Group / Mayly Sanchez; **Fermilab CD Liaison** Andrew Norman
    - **Software releases and production** Davies / Mayer
    - **Database coordinator** Jon Paley
  - **Physics analysis coordinator** Ryan Patterson
    - **Detector simulation** Jim Musser / Alex Sousa
    - **Beam data and simulation** Bob Zwaska / Raphael Schroeter
    - **Reconstruction** Peter Shanahan
    - **nue and NC** Mayly Sanchez / Tricia Vahle
    - **numu CC** Jon Paley / Greg Pawloski
    - **Exotics** Craig Dukes / Alex Habig

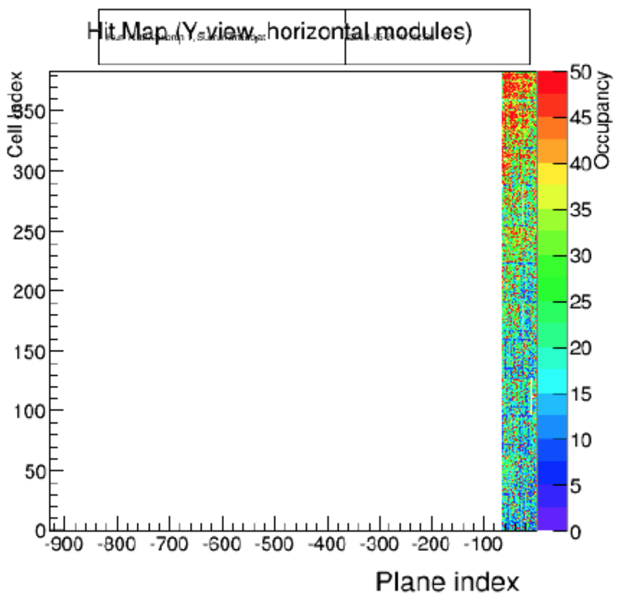
We have tried to encourage analysis groups to use common tools as much as possible.

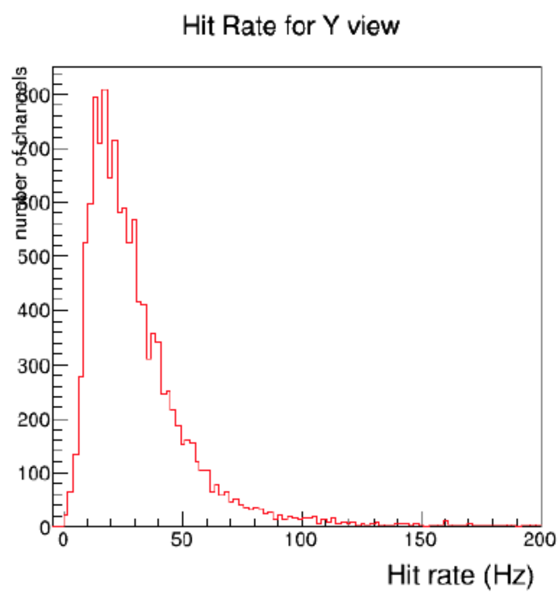
Most groups meet biweekly.

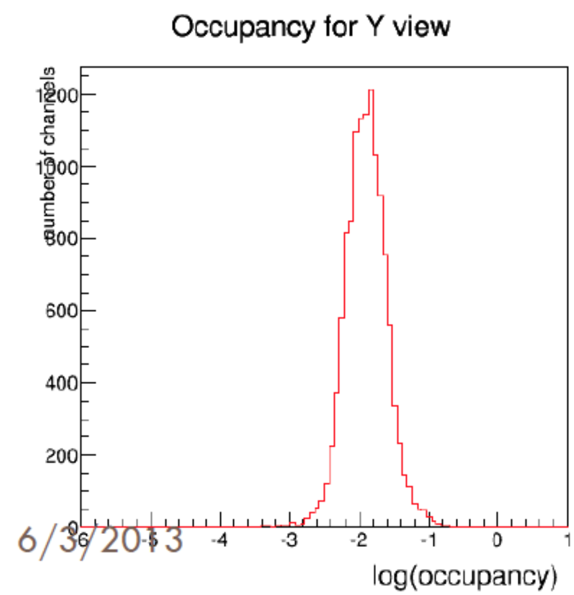
All of the conveners also meet every few weeks.

Detector Operations

- Online Monitoring / Event Display for real time monitoring of low level measures: hit rates, charge, time, trigger rates, error bits, etc.
- Nearline: ~1 hour feedback to shifters from fast reconstruction, cosmic ray rate, timing and synchronization information, etc.

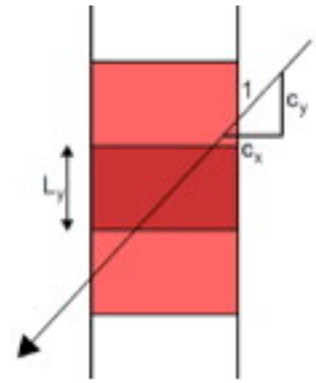


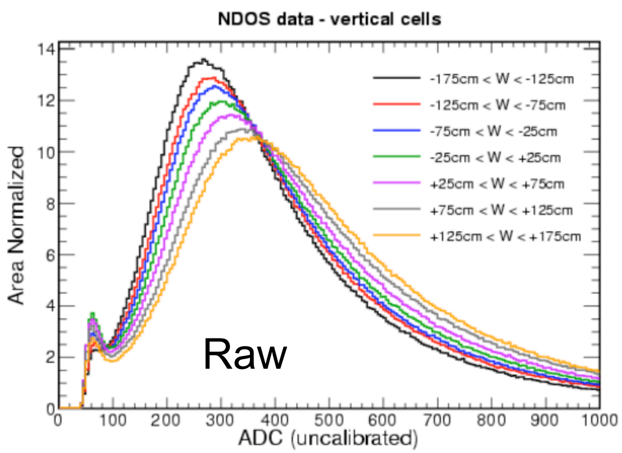


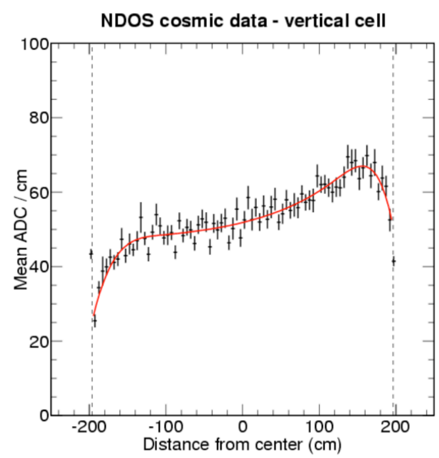


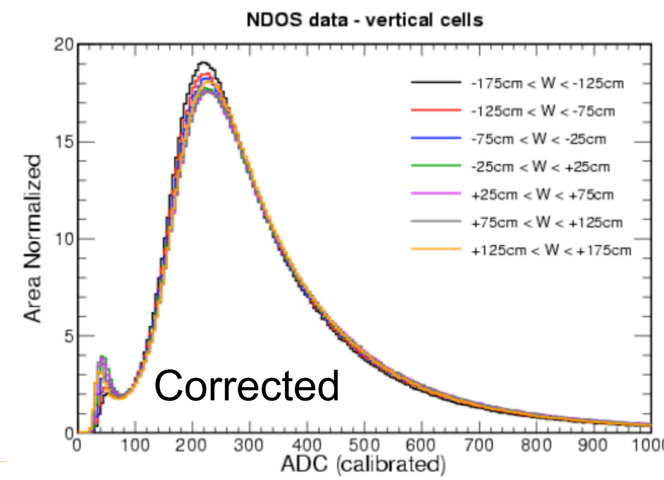
Calibration and Alignment

- Cosmic ray muons are used for all of the calibrations, abundant in the far detector and adequate in the near.
  - Cell by cell amplitude drift and attenuation
  - Absolute amplitude from stopping muons
  - Cell by cell timing
  - Block by block alignment







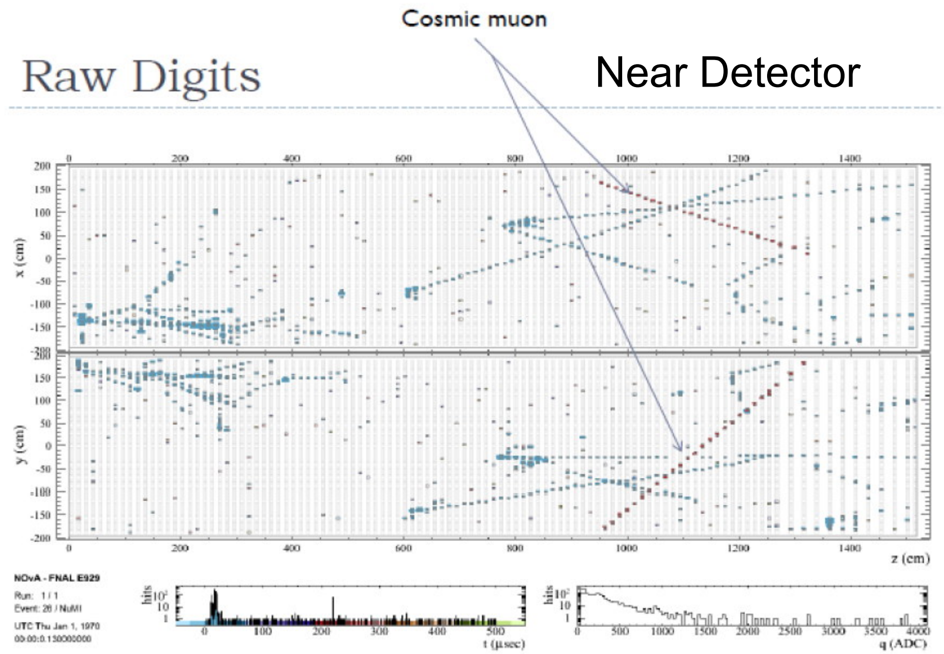


Beam Simulation Group

- To the extent possible, all three NuMI users, NOνA, MINOS+, and MINERνA are working together on exchange of beam information.
  - Common ntuples for beam files
  - Comparisons between different Monte Carlo models are being made.
  - Complementary information from MINOS+ and MINERνA on-axis detectors and NOνA's off-axis detector.

Detector Simulation Group

- All parts are in good shape, beam events, rock events, and cosmics. One present project is to produce overlay files.
- Another effort is to increase efficiency.
- Other technical details.

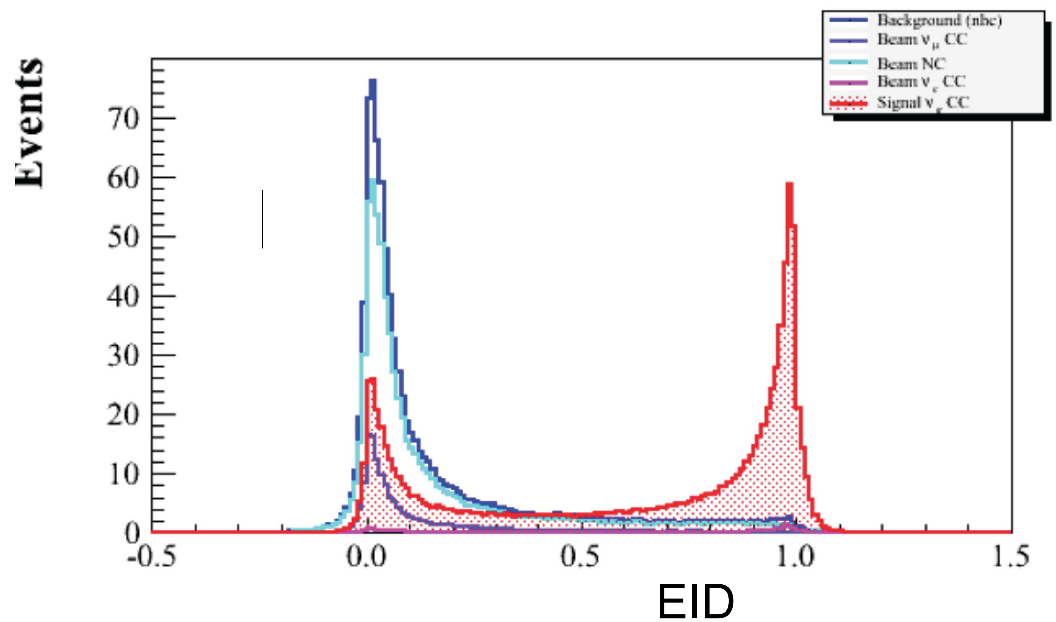


Reconstruction Group

- The Reconstruction Group is a forum for discussing mid-level routines of interest across analysis packages.
- Examples include slicers, trackers, and vertex finders.
- For the past couple of years we have been in a "Let a hundred flowers bloom" mode. But now we are converging rapidly to the best performing routines.

ν_e and NC Group (1)

- 1st major task is to identify ν_e CC events from a background of mostly NC events.
  - We have two methods with high and equal figures of merit but completely different approaches and systematic uncertainties.
    - EID: Neural net on high level event parameters.
    - LEM: Library event matching on energy deposits in detector cells.

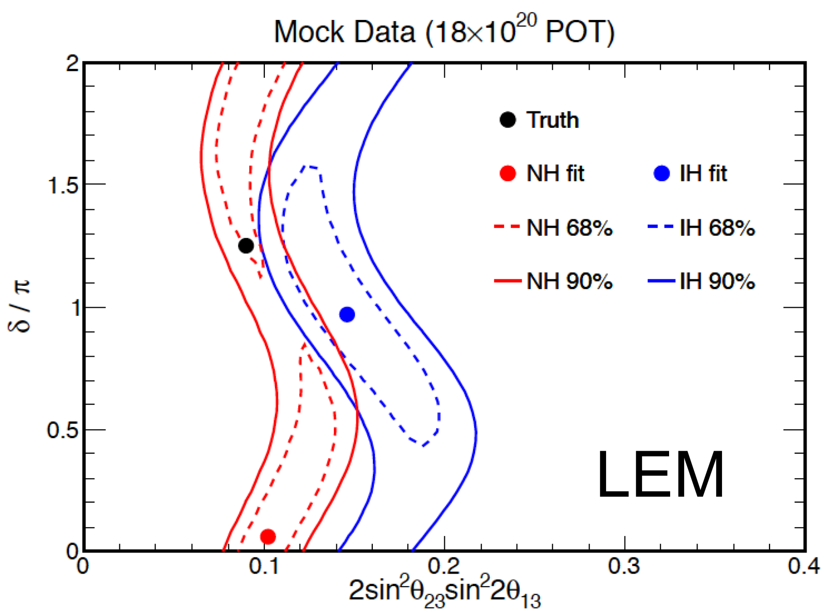


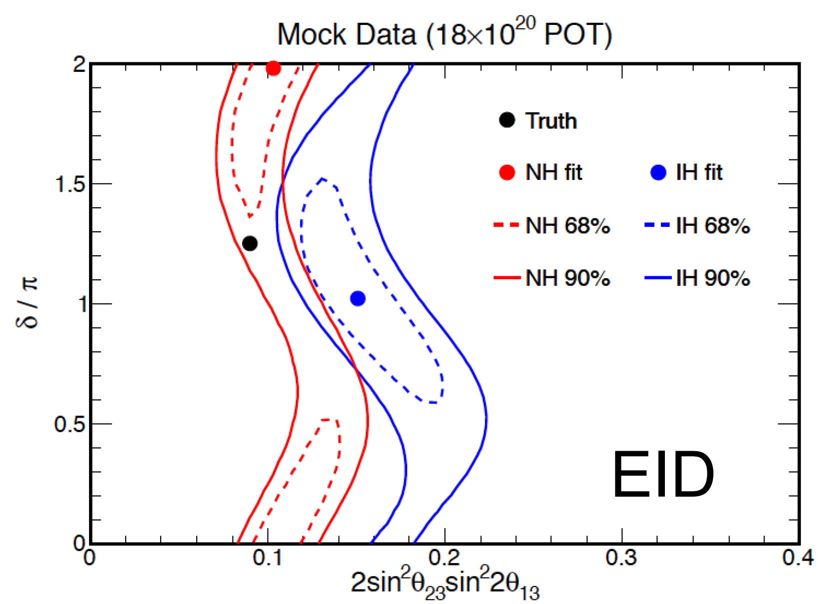
ν_e and NC Group (2)

- 2^{nd} major task: Extrapolation from the ND to the FD
  - We need to extrapolate identified ν_μ CC and ν_e CC backgrounds.
  - There are 3 components to the ν_e CC backgrounds (ν_μ CC, beam ν_e CC, and NC) and they all extrapolate differently.
  - We would like to use data-driven techniques to separate the three classes of backgrounds as much as possible. We are exploring three techniques:
    - Muon removed ν_μ CC events to simulate NC events.
    - The existence of Michel electrons in the events.
    - Horn on/horn off comparisons.
  - Comparing the left and right halves of the ND is a check.

Mock Data Challenge (1)

- Last fall we did our first mock data challenge. Hidden physics parameters were chosen and all truth information was stripped from the Monte Carlo files.
- Results were reported at our January collaboration meeting. The two analysis techniques got identical results, which agreed with the truth within about 1 σ.



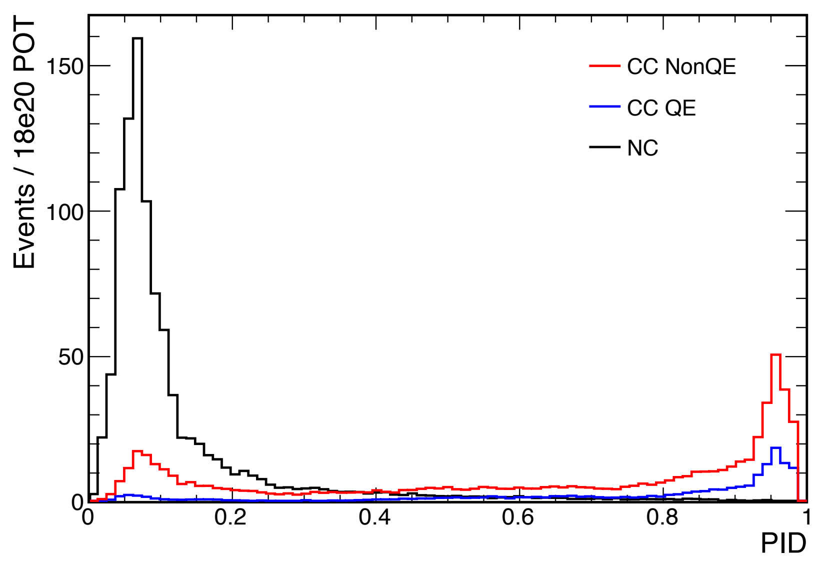


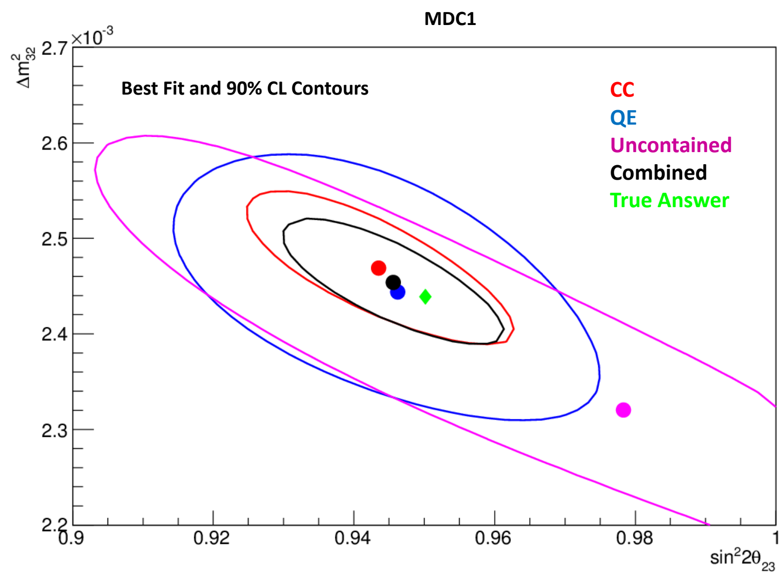
Mock Data Challenge (2)

- Note: These results do not represent NOνA sensitivity. There are no $\bar{\nu}$ data or reactor constraint on θ_{13}.
- This data challenge was only on far detector data. We plan another data challenge later this summer that will include near detector data and an extrapolation to the far detector.

ν_μ CC Group

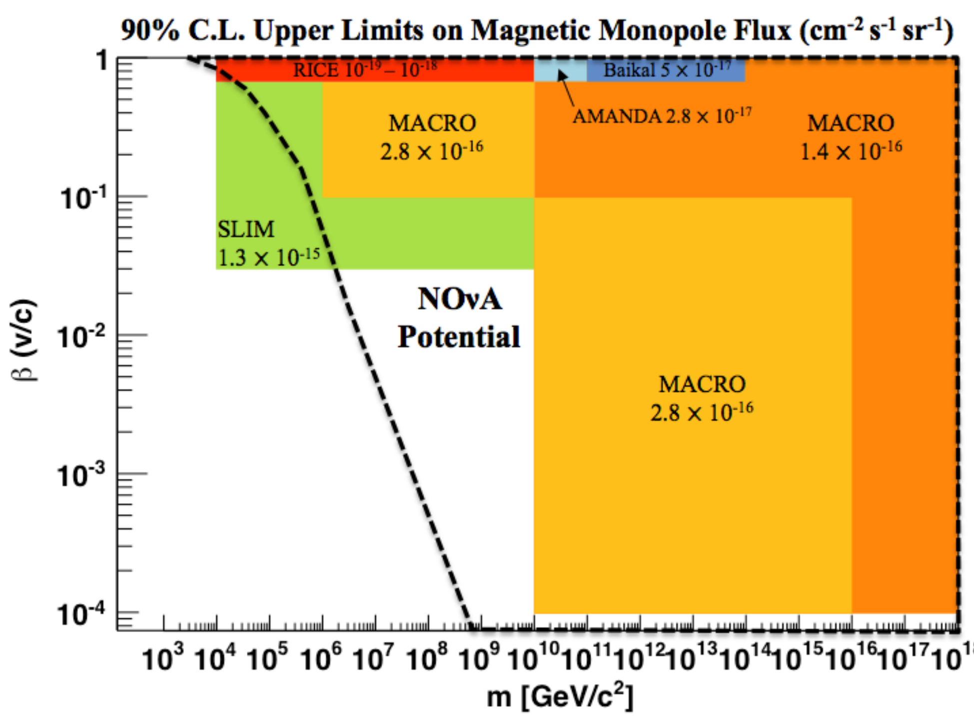
- Similar situation to the ν_e group:
  - One good event ID, ReMID, based on maximum likelihood analysis.
  - Concerns are QE identification, energy resolution, and cosmic rejection (10^{-5} needed).
  - Spot on in the mock data challenge.





Exotics Group

- This group is working on a number of “exotic” measurements. The two which have received the most attention are
  - Supernovae detection. the most challenging problem is the rejection of cosmic ray debris.
  - Monopole search. Due to our thin over-burden, there is a unsearched region of phase space open to NOνA.



Data-Driven Triggers

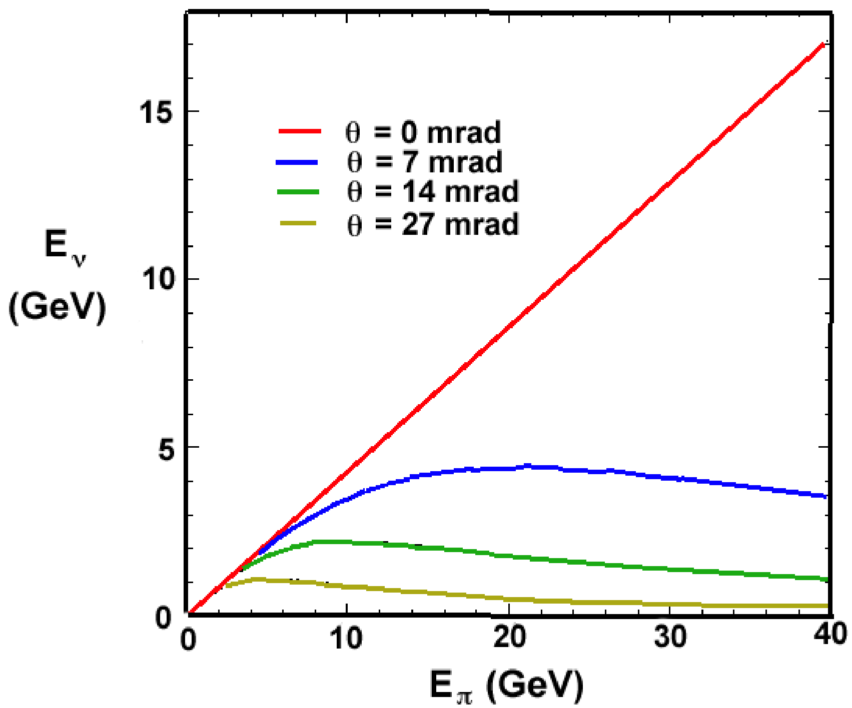
- Unlike MINOS, we cannot record everything that is happening in the far detector due to the 100 kHZ cosmic ray rate. So we have been developing three general classes of data-driven triggers:
  - Non-beam physics: exotics, upward atmospheric ν's, etc.
  - Rarer cosmics useful for calibrations: stopping, horizontal, Brehming, etc.
  - Backup for beam events.

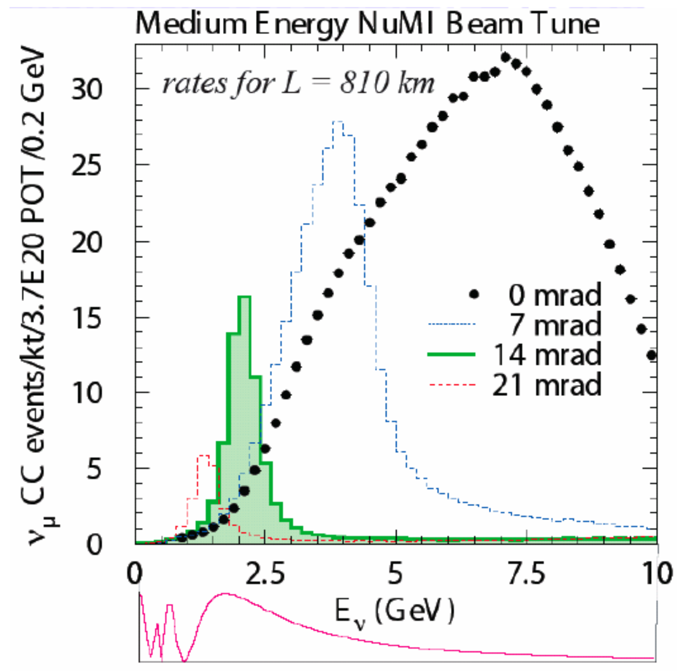
Summary

- We are ready to take advantage of beam that will start in less than three weeks.

Backup Slides

Off-Axis Beam

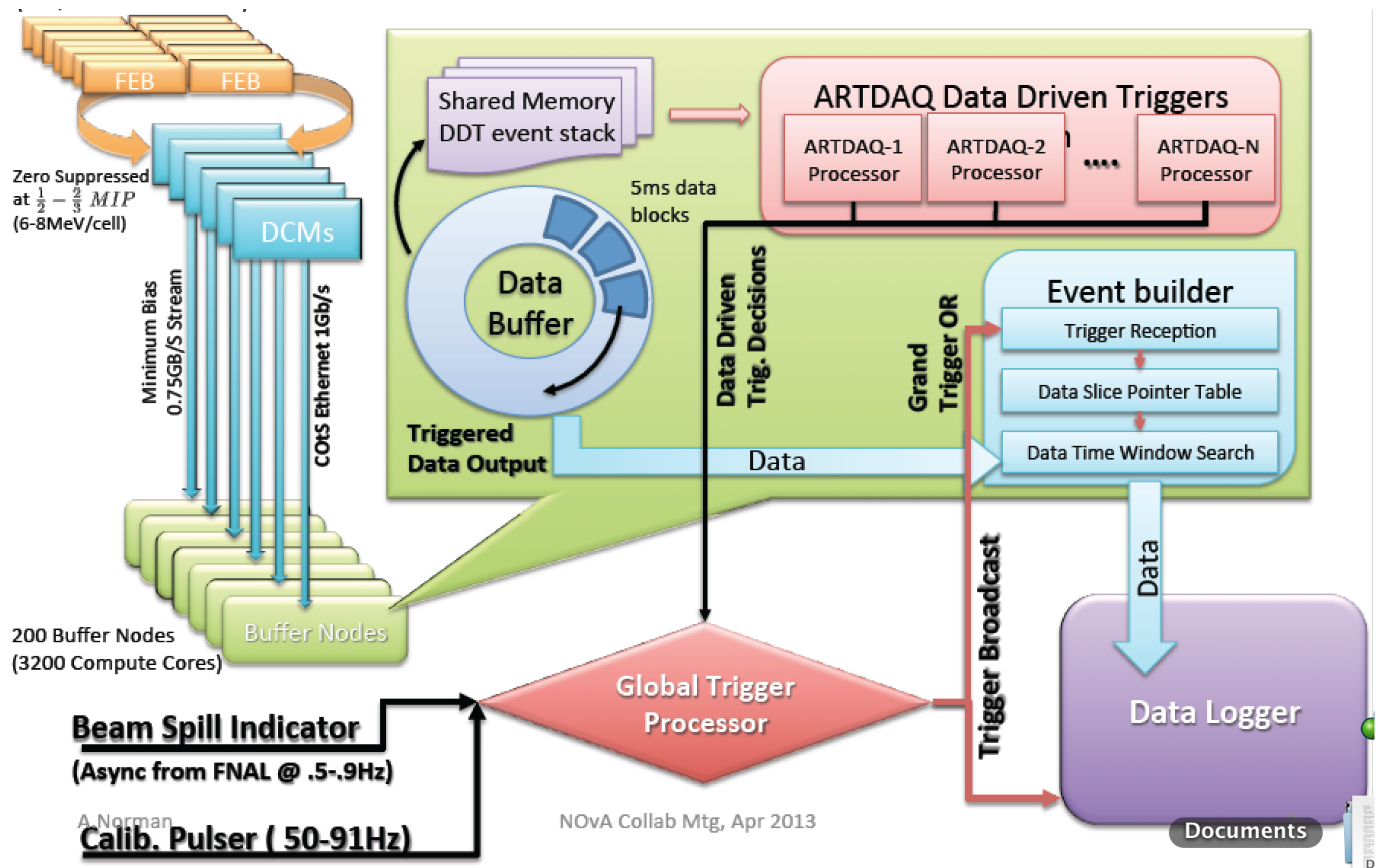




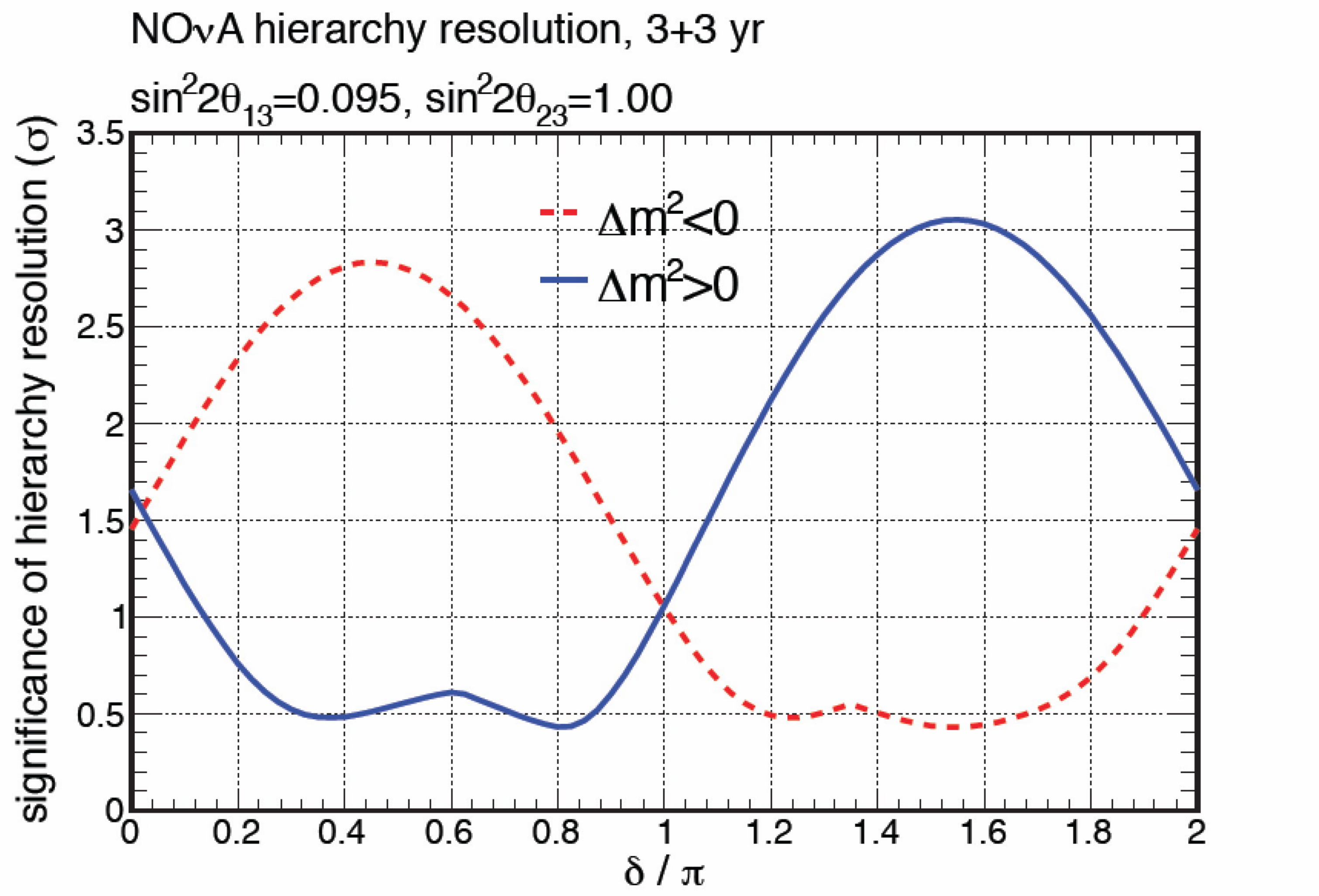
Moving a Finished Block

Placing a Block

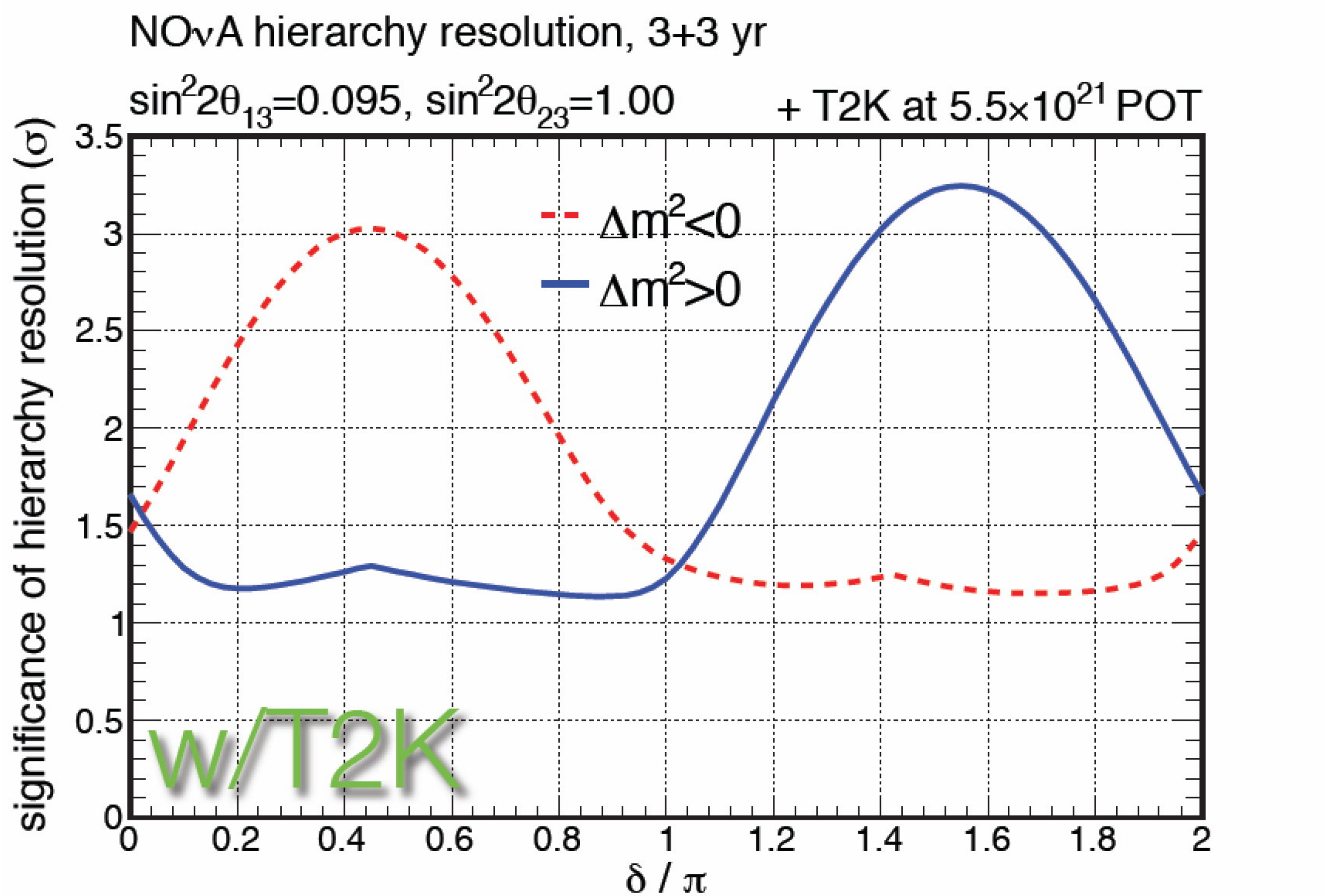
Data-Driven Trigger Scheme



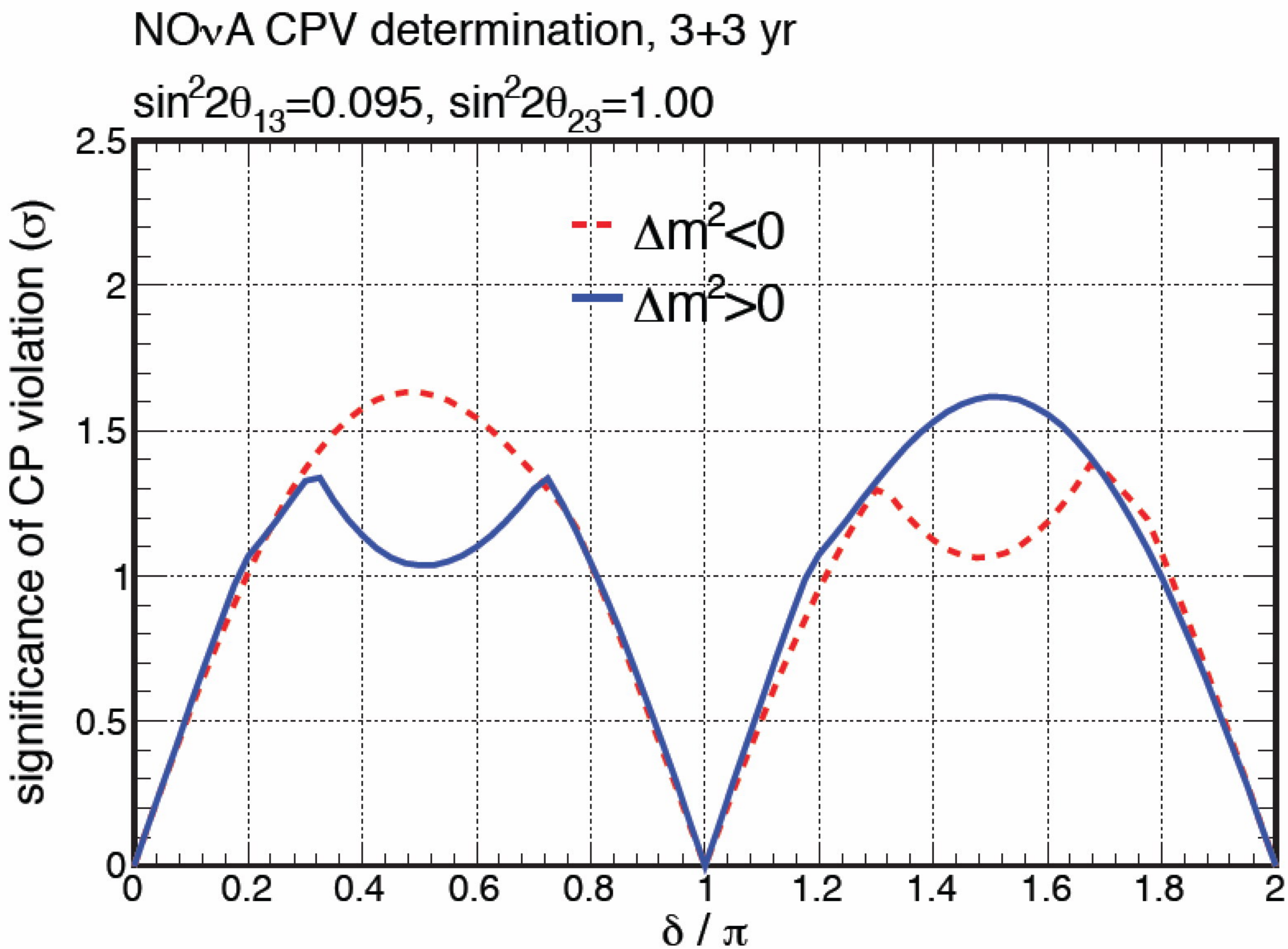
Mass Ordering Sensitivity NOνA Alone



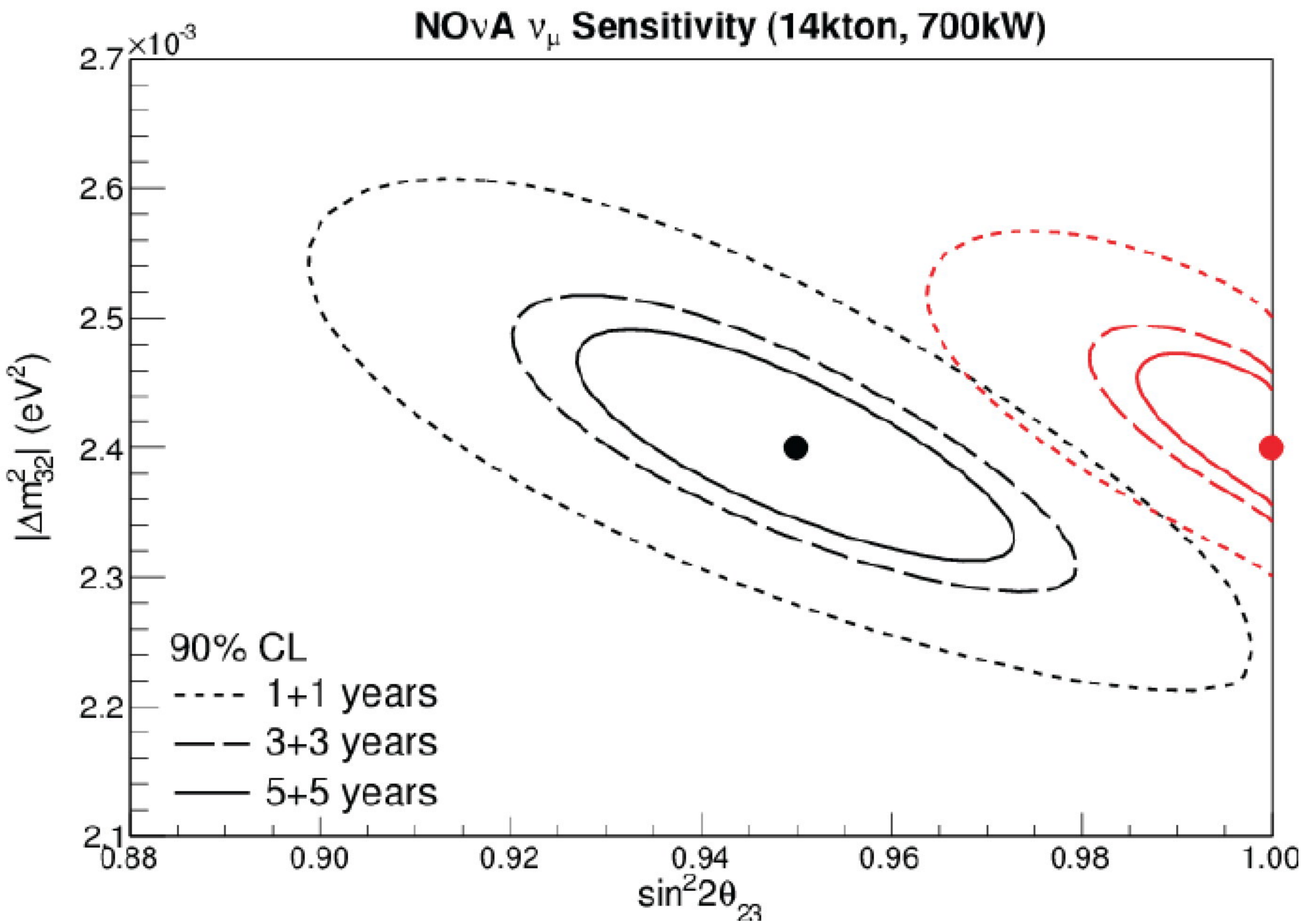
Mass Ordering Sensitivity NOνA + T2K



CP-Violation Sensitivity



θ_{23} Sensitivity from ν_μ Disappearance



θ_{23} Quadrant Sensitivity